SCIENCE AND ENGINEERING, ESSENTIAL ELEMENTS OF NATIONAL STRENGTH AND SECURITY

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The social and economic system of which we are a part is founded on scientific and engineering accomplishments of comparatively recent origin, and its health and vigor are directly dependent on continuing advances in scientific knowledge and their imaginative application by designers and engineers to meet social and individual needs. In the international climate of today, the very security of the free world is the stake in the cold war competition for over-all position in science and technology. The requirement is not for application of our knowledge and skill to clever gadgetry to make our lives more comfortable but to advanced weapons and advanced scientific and technological accomplishments which lay the foundation for the weapons of the future. We need better airplanes, improved guided missiles, more effective radars and communication systems, and we need satellites and space craft, if necessary, at the expense of some of the luxuries of our present daily lives.

Having these views, I am gratified to see in the reports of this symposium the evidence of a large amount of scientific and technical activity in the many fields of science and engineering that support the development of military weapons. Contributions in propulsion; materials; electronics, including radar, communications, guidance and control; meteorology; aero- and space-medicine; nuclear engineering; and systems engineering are to be found in your program. These papers add essential new data to our store of knowledge and describe new developments that contribute to national security.

The past year has been one filled with fast-moving events. It has brought great changes in the technology which concerns us, including the coming of age of the long-range ballistic missiles which have been under development for some time and the appearance in the sky of the first man-made satellites of the earth. My own organization, the National Advisory Committee for Aeronautics is in process of great change. There is on the President's desk for signature a bill establishing the National Aeronautics and Space Administration built around the present NACA which will soon be abolished. The new agency has responsibility for the non-military aspects of space activities, including space science, technology, and exploration as well as the present responsibilities of NACA in the aeronautical field. The NASA will cooperate with the military services and support military development projects in both fields as the NACA has supported aeronautical and missile projects in the past.

The history of military aeronautics illustrates the predominant role of science and engineering and the dynamic progressive growth of science and technology that is required to assure a place of leadership. The growth of aeronautics has been an evolutionary one marked by continually increasing speed and altitude of aircraft and missiles until now we are on the frontiers of space. This performance improvement has been made possible by a gradual increase in knowledge in aerodynamics, propulsion, and structures punctuated by several large step-like, or as the physicist would say, quantum jumps. Thus in aerodynamics we learned to reduce drag by proper location of engine and propellers illustrated in the modern propeller transports, and to postpone compressibility by proper shaping and reducing the thickness of wing sections as in present jet fighters, bombers, and transports. We had the "breakthrough" of the area rule which immediately made possible supersonic fighters and bombers.

Similarly in propulsion and structures. In propulsion we gradually increased the power of reciprocating engines by increasing compression ratio, adding more cylinders, and improving the fuel. Then came the sudden step-like increase in power and decrease in weight available in the jet engines and rockets. In structures we advanced from wood-and-wire to metal with more and more sophisticated design, and were able to reduce the ratio of structural weight to gross weight notwithstanding the tremendous increases in speed which imposed greater loads as well as introduced aeroelastic and flutter problems of great difficulty. All of these advances were interdependent. Jet engines were useful only at the high speeds which became practical only after structural developments which permitted the thinning of wings to reduce drag. In the over-all performance curves the large improvements are somewhat smoothed out so that the curve is fairly smooth. But the sharp rise in the annual rate of increase of maximum speed when jet power was introduced is plainly evident.

We now have the very great increase of performance made possible by the large rocket engines which can boost our vehicles into the regions of space where air resistance becomes minute and the forces of gravitational attraction and inertia are predominant. Here too, although the slope changes, the curve will have a continuous upward trend. At first, before we put large space stations into orbit, we will be dealing with vehicles which are launched through the atmosphere and which must re-enter the atmosphere, be slowed down without destruction by heating, and finally land. The major problems of these vehicles are akin to those of present airplanes, differing only in degree. Their solution requires only an extension of research into new regions of speed, temperature, and pressure. These vehicles will always be needed as will our present type of airplanes.

As space technology advances, the true space or interplanetary vehicles will appear. In the development of these, new problems will have become dominant. The structures no longer will be subject to large forces over large areas, they will use light structural members, and involve new materials which seem strange at present.

Once space vehicles have completed the first phase of their journey, propulsion will no longer require large thrusts and fuel economy will be the dominant consideration. Some type of electrical propulsion system, ion or otherwise, becomes attractive. Our engineering compromises will move toward engines of thousands of pounds weight per pound of thrust. However, fuel consumptions of as little as one percent of those associated with present powerplants will be achieved.

The provision of internal power from nuclear reactors or solar power, navigation, guidance and control, communication, suitable environment for man -- these and many other problems will require very different solutions from those we now use. The greatest demands will be made on our research and development capabilities as we venture farther and farther into space.

I have proceeded from the past of 50 years ago through the present to many years in the future to emphasize the continually changing aspect of the technology, its evolutionary nature, the occurrence of step-like advances, sometimes called breakthroughs, and the heavy demands on basic and applied scientific research and on advanced engineering techniques to maintain a high rate of progress.

The launching of the first man-made satellite on October 4th of last year produced an intense emotional reaction which for a time made it difficult for all of us to view the scientific and technological situation with proper perspective. Scientists and engineers in the weapons field have a special responsibility to the men who will ultimately use the weapons they create. They must be bold and imaginative, yet realistic and practical. There is need for scientific and engineering integrity in the evaluation and assessment of the expected performance. Never in the history of technology have there been so many fruitful ideas to be explored by research, and never have the costs of engineering development of new weapons been so high. Never has there been a greater need for exploitation of the best ideas, lest our enemies do so first. The task of assessment and selection is difficult but necessary, and can be successful only if approached as objectively as possible.

Weapon system development rests upon a broad base of scientific knowledge, the results of fundamental and applied research. The final quality of our weapons depends on the extent and soundness of this foundation. Just as the foundation of a building is not easily visible when the structure is completed, so the research behind a new weapon is not easily seen in the completed weapon. By then the basic research done some years before is no longer new and is replaced in the public eye by the research of today which is the foundation of tomorrow's weapons. The development of weapon design is impossible without accompanying advance in scientific research. The ancestry of a new weapon leads not to a single research project but to many research projects carried out at many institutions and even in many countries. The base of the pyramid of research incorporated in any one weapon is very broad.

Research advances knowledge by isolation of limited aspects of development problems which are analyzed by specialists in specific fields. The designer of a weapon must, on the other hand integrate many such research results and solve <u>all</u> of the many problems at one stroke in a single prototype. Thus design is more of an art than a science, and the designer must be able to synthesize information from many sources, including that resulting from past experience as well as that derived from the limited but controlled experience studied by the scientist.

The application of science to design, especially "the extent to which design could be made rigorously subordinate to scientific rules", to use the phraseology of the late E. P. Warner in 1932, was once a matter of extensive debate. Engineering judgment resulting from practical experience was the chief qualification of the best designers. Today we recognize that engineering judgment must also be applied with full knowledge of the best that modern science can offer in the knowledge and understanding of the phenomena of Nature -- how air flows around bodies; the behavior of materials and structures under static and dynamic loads; solid state physics; information theory; human physiology and psychology; microwave generation and transmission; nuclear physics; and many of the other components of the great edifice of human knowledge.

It is immediately apparent that we are discussing knowledge far beyond the capabilities of any one individual to digest and use. In both design and scientific and engineering research we have met this problem with the social invention of the design team and the research team consisting of many individuals with differing qualifications, but as a group covering the field. During my lifetime both design and research have expanded from the solo effort of the inventor and cloistered scientist to the symphony of the design team and the research group. We once knew the name of the designer of an airplane or the name of the scientist who first introduced a new contribution. Today we deal more often with the product of a group and the custodians of awards and prizes for individual contributions are having ever-increasing difficulty.

In the earlier stages of this development the problems attacked could be broken down into specialized problems which could be assigned to different individuals or groups to work out the optimum solutions. There was little interaction between problem areas, and the few interactions that did exist could be handled by small correction factors. Thus in the design of aircraft about 15 years ago, the design teams were broken down into an aerodynamic group, a power plant group, structural group, electrical group, hydraulic group, etc. The most necessary coordination was to provide adequate space and to check that mating parts would fit. The only interaction problems were propeller slipstream effects on the aircraft drag, stability, and control and the drag associated with cooling.

As airplane speeds increased, the mutual interactions became much larger. The effects of the large air flow into and out of jet engines are so great that separation of engine thrust and airplane drag is almost a matter of definition. Experiments on the aerodynamics of the whole configuration with actual or simulated power plant operation become almost indispensable. Radio and radar antennae must be designed for low drag as well as for excellent electrical performance. The mutual interactions between aerodynamic load and structural deflection introduce the cross-discipline problems of flutter and aeroelasticity. Methods of system analysis are required as well as a new concept of team activity in the functional coordination of the various sub-systems. The team must include more kinds of specialists with knowledge of more scientific fields. Such teams designed our current airplanes and missiles. The further evolution of this philosophy of design supported by a vigorous activity in scientific research will expand actual and possible accomplishments and proposals hitherto unrealizable, for example, interplanetary flight, will become practical engineering projects.

The research programs in the sciences basic to weapon development need the interest and support of informed citizens and of the Executive Agencies of government and the Congress. In particular there must be a greater awareness and support of the longer range programs of basic research, which provide the supply of material not only for swords but for pruning hooks as well.